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The Air Traffic Control Operational Errors Severity Index: An Initial Evaluation

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16. Abstract <p>An initial evaluation of the Federal Aviation Administration's (FAA) Air Traffic Control (ATC) Operational Error (OE) Severity Index (SI) was conducted by the Civil Aerospace Medical Institute's (CAMI) Aerospace Human Factors Research Division (AAM-500). The SI is computed from data that, for the most part, can be objectively determined by post hoc investigation of OEs. Up to 100-points are assigned for varying levels of vertical separation, horizontal separation, closure rate, direction of flight paths, and the amount of controller awareness at the time of the OE. Based on the point totals, OEs are classified as: low (D), low moderate (C), high moderate (B), and high severity (A). This review and subsequent analyses focused on three key issues: (1) the distributional characteristics of operational errors, (2) the collision safety margin associated with SI point values, and (3) the objectivity associated with SI classifications of high moderate and high severity OEs. We concluded that the SI provides a rational approach for categorizing the severity of ATC Operational Errors. Although questions remained as to the SI cut scores used to categorize OEs, it was recommended that the cut scores should not be changed unless objective measures can be developed to support those changes.</p>			
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THE AIR TRAFFIC CONTROL OPERATIONAL ERROR SEVERITY INDEX: AN INITIAL EVALUATION

Currently, the FAA Air Traffic Investigations Division oversees and coordinates the Operational Error (OE) reporting process governed by the FAA Air Traffic Quality Assurance Order 7210.56c (FAA, 2002) that details the conduct of incident reporting processes. The need for a formal, system-error reporting program was recognized early in the FAA's evolution. Recommendations were developed regarding the conduct of incident investigations and the use of the resulting information, many of which were incorporated into the FAA Order 8020 (O'Connor & Pearson, 1965). In 1964, a six-month test of an expanded operational error/operational deviation (OE/OD) reporting form was conducted at two en route centers located in Miami and Jacksonville, Florida. By July 1965, FAA Order 8020, the AT System Error Reporting Program, was revised "to provide more complete error occurrence information and simplify typing with a resultant savings in time" (League, 1965). In addition to many items resembling those used in the current report, this form included a matrix of points assigned to horizontal and vertical separation. This information was used to categorize the event as major, moderate, or minor, using horizontal and vertical proximity. Although this matrix was later discontinued, the system was continually revised to become the current operational error reporting system (FAA Order 7210.56c). The error reporting system has demonstrated the relatively infrequent nature of OEs. For example, in fiscal year 2000 alone, the U.S. air traffic system handled 166,669,557 operations with an OE rate of .69 per 1000,000 facility activities. (FAA, 2002). However, concern has been expressed that the error rate has gradually increased from .49 in 1997.

In response to a recommendation in the 2000 report by the U.S. Department of Transportation's Office of Inspector General (OIG), the FAA developed a method to assign severity values for operational errors that occur in flight. A memorandum of understanding was negotiated between the National Air Traffic Controllers Association (NATCA) and the FAA to support this effort. Having a tool to group OEs by severity would facilitate the prioritization and allocation of resources to focus attention more efficiently on OEs in the different severity groups. Later, in 2003, an OIG report (hereafter called the OIG report) led to a scientific evaluation of the OE Severity Index (SI) and its component parts. We report on the results of that evaluation.

Operational Error Severity Index (SI)

A study of OEs throughout the National Airspace System (NAS) served as the basis for development of a model that would characterize their severity (Rodgers & Nye, 1993). Information from the initial investigation was used as the basis for development of the current SI. The index is based on the following factors: vertical and horizontal separation distances, relative flight paths, cumulative closure rates, and the level of ATC awareness (hereafter referred to as ATC Control). Since these factors are based on operationally relevant criteria associated with the provision of ATC services, they allow for the calculation of the severity of air traffic control separation losses. These factors are allocated various point values that total 100 and thereby allow for an assessment of relative safety across operational errors.

The current Severity Index formula is computed from data that, for the most part, can be objectively determined by post hoc incident investigation. Points are assigned for varying levels of vertical separation, horizontal separation, closure rate, flight paths, and the amount of control. Determination of whether the event was controlled or uncontrolled is the only variable that requires ATC expert judgment to determine a point value.

Vertical and Horizontal separation are defined as the minimum separation based on the radar data just prior to aircraft divergence. Together, these factors make up to 50% of the SI point total. As shown in Tables 1a and 1b, the maximum point values (25 points each) are assigned for both vertical and horizontal distances for events that culminate in proximities of less than 500 ft vertical and less than ½-mile horizontal separation. Given existing radar tolerances and measurement tools, further division of minimum separation distance would be of limited value. Accepting the notion that the safety margin decreases geometrically, as opposed to a steady arithmetic decline as aircraft get closer, points assessed for close encounters remain higher. Conversely, as vertical and horizontal separation increase, the potential threat to safety is assumed to be lower, and their associated point assignments drop off rapidly.

When wake turbulence separation standards govern aircraft around an airport, SI point values for vertical separation are not calculated. Instead, in-trail separations point values are used, as shown at the bottom of Table 1b.

Respective point values for closure rates and flight paths were developed to objectively include these parameters as components of the Severity Index (Tables 1a-1b). It should be noted that faster aircraft closure rates, coupled with converging, opposite-direction flight paths reduce the safety margin more so than slower closure rates and diverging flight paths. Also, a significant assumption is made that aircraft on diverging or non-intersecting paths have little impact on the overall safety margin and consequently do not receive Severity Index points. However, head-on encounters at high rates of speed, coupled with minimum radar data separation distance prior to divergence, account for the greatest total point value. The highest possible point values assigned to closure rate and flight path determinations make-up 10% and 20%, respectively, of the index.

A final factor, ATC Control, completes the assessment of severity for each airborne operational error. While the main purpose of the ATC system is to preserve safety, determining the adequacy of ATC services assists in understanding shortfalls that occasionally occur; therefore, ATC Control is included in the model of error severity. As with the other factors, an initial assumption is made that maximum point values are assigned when the controller was unaware of the conflict, took no corrective action, and/or became aware of the conflict but did not have sufficient time to effectively mitigate the loss of separation (20% of maximum index score). For encounters in which a controller is aware of the impending conflict and issues control instructions insufficient to attain required aircraft separation distances, minimum point values are assigned for this factor, as it is considered a controlled event (4% of maximum index score). For events in which a Traffic Alert and Collision Avoidance System Resolution Advisory (TCAS- RA) is initiated and the controller was taking actions to mitigate the event, an intermediate point value is assigned (15% of maximum index score). The ATC Control component of the Severity Index was introduced in April of 2002.

While an initial estimate of the overall point total for an OE is determined as part of the preliminary report, a specialist at FAA Headquarters reviews each of the events and assigns the final rating. The point total for an event can range from 12 through 100. As a part of this effort, three severity levels were initially established. High Severity events have a point range from 90 to 100. Moderate events range from 40 to 89 points, and Low Severity events have a rating of 39 or less. Later, the Moderate category was further divided into Low and High Moderate, primarily based on whether the controller was aware (Low Moderate) or not aware (High Moderate) that an error was occurring at the time of the closest loss of separation.

The following is an example of how the point total is used. If an aircraft is in en route airspace at a higher altitude, standard separation calls for the minimum separation to involve either a horizontal distance of 5 miles or a vertical distance of 2,000 ft. As separation between aircraft is reduced to less than the required distance, points are assigned for the moment when minimum separation occurred. If the aircraft pair was separated by less than 500 ft vertically (25 points) and between 1 to 1.499 miles (24 points), the subtotal would reach 49 points. At a closure rate of 300 to 699 knots, an additional 8 points would be added. If the flight paths were converging on a crossing course, another 18 points would be added. The final factor included in the algorithm involves a decision regarding the controller's awareness of the event. If it was uncontrolled, a situation where the controller was not taking action to avoid the loss of separation, another 20 points would be added. This is the only factor of the Severity Index where subjective judgment plays a role. All other information is available from objective sources. For this particular event, the point total is 95, placing this event in the High Severity category

As part of an evaluation of the FAA's SI, this report focuses on three objectives: (1) to evaluate the SI and identify the relationships between components of the SI, (2) to examine the aircraft safety margin associated with SI point values, and (3) to examine the cut score used to differentiate between High Moderate and High Severity OEs. The analyses were designed to evaluate the relationships between loss of separation from the prescribed standards and the Severity Index, and to identify ways in which the index can be used to support efforts to develop strategies that will mitigate the severity of OEs.

METHODS AND PROCEDURES

Index Scores

The OE database contained 2,390 OEs that occurred between April 2001 and May 2003. Missing values in 394 cases left a total of 1,996 OEs with valid index scores. Of the 1,996 cases, 572 involved the En Route 2,000 ft requirement, 723 for the En Route 1,000 ft requirement, 679 were Terminal and En Route Single Site Radar (TE-Single Site), and 22 were Wake Turbulence.

Severity Index Variables

The OE SI is a function of five variables. Vertical Separation (feet), Horizontal Separation (miles), Closure Rate (knots), Flight Path (converging – opposite course, converging – crossing course, same course, diverging/nonintersecting), and ATC Control (Uncontrolled, Controlled no TCAS RA, and Controlled with TCAS RA). The only subjective component is ATC Control.

Statistical Analysis

Descriptive statistics were used to assess the distribution of the SI components. Correlations between each of the rating categories that comprise the SI and the SI scores were computed to better understand the relationships between the ratings and the overall SI score. For these analyses, we used the actual vertical and horizontal separation distances and the ratings for the closure rate category. Flight Paths were categorized as follows: Converging–Opposite Courses (1), Converging – Crossing Courses (2), Same Course (3), and Diverging/Non-Intersecting (4). The ATC Control Factor events were categorized in a similar fashion: Uncontrolled (1), Controlled with TCAS RA (2), and Controlled with no TCAS RA (3).

To examine the aircraft safety margin, ten loss-of-separation categories were created based on the percentage of available separation (10% or less through 91% to 100% of the separation standard) for horizontal and for vertical separation. Next, we determined the number and percentage of the OEs that fell within each of the ten loss-of-separation categories. These were determined for each of the three separation standards (En Route 1,000 ft, En Route 2,000 ft, and Terminal and En Route Single Site Radar). Finally, we calculated the average SI score for the OEs that were present in each of the ten categories defined above. To illustrate these differences graphically, we collapsed the ten loss-of-vertical separation categories into five categories to simplify the illustration. We then plotted the percentage of OEs in those categories against the ten horizontal loss-of-separation categories.

Discriminant analyses were conducted to determine whether there was subjective bias associated with differentiating between High Moderate and High Severity OEs. The goal of the discriminant analysis was to develop an equation that classified OEs into these two categories based on the SI components. The classification results were then compared with the results of classifying OEs using the SI. A high degree of correspondence between the comparisons would indicate that the SI is consistent with the objective data. Similarly, a low correspondence between the comparisons would indicate that the SI was inconsistent with the objective data. Moreover, the weights assigned to each of the predictors were compared with the weights used in the current SI. A high degree of correspondence between the comparisons would indicate that the SI system of weighting was consistent with empirically derived weights. Objective values of vertical and horizontal separation, closure rate, and flight path, along with a subjective measure of ATC Control (no objective measure exists), were used to classify OEs. However, in contrast to the values used in computing correlations, the ATC Control factor was dichotomized: 1 = controlled,

and 2 = uncontrolled. Separate analyses were conducted for the three separation conditions: En Route 2,000 ft, En Route 1,000 ft, and TE- Single Site.

It should be noted that the results of the discriminant analyses cannot be directly compared with the results of the correlations. This is because the two statistics are computed over different portions of the SI. The correlations are calculated across the entire SI range. In contrast, the discriminant analyses are conducted for SI values greater than 79. Since the area of interest for the discriminant analysis is the cut score separating High Moderate OEs from High Severity OEs, it is important that the focus of the discriminate function should be on OEs within the region of dispute. If the total range of High Moderate (70-89) is used, the classification results will be inflated due to the high base rate associated with this category.

RESULTS

Descriptive Statistics

Descriptive information regarding the components of the OE SI is provided in Table 2. There was considerable variability in vertical separation, mean of 621 ft and SD of 484.49. In contrast, the horizontal separation had a SD of 1.34 around the mean of 2.932 miles.

Nearly one-half of the OEs involved a Diverging/ Non-Intersecting flight path where no points were added for either closure rate or flight path. With the exception of OEs where the closure rate exceeded 699 knots (2.51%), the percentage involving the three other closure rate categories was relatively consistent, ranging from 13.53% to 18.69% of the OEs. Only a small percentage of the OEs involved converging, opposite-direction flight paths (5.21%) or Same Course headings (9.12%). Nearly 75% were considered to be Uncontrolled events (70.84%). A small percentage was considered as a Controlled event that involved a TCAS RA (2.15%). Diverging flight paths involved a higher percentage of Controlled-No TCAS RA events (42.8%).

When severity scores are used and only those OEs that have been assessed by this metric to date utilized, the distribution reflects a somewhat negative skew as shown in Figure 1. A majority of the errors (73.1%) fell in the Moderate Severity group. The High Severity category involved 5.47% of the OEs, and the low comprised 21.44% of the OEs. This is similar to the sample used for the OIG report: 8% high, 72% moderate, and 22% low.

Correlations between the SI score and the rating categories that comprise the index under the three separation standards and across all conditions (overall) are presented in Tables 3a through 3d. The small number of instances where the OEs involved Wake Turbulence

made the use of those correlations of limited utility. For the three separation standards, correlations between the rating categories were generally low to moderate. The exception was the consistently high correlations between Flight Path and Closure Rate (ranging from -.85 to -.97). This is understandable when one considers that the highest closure rates occur when aircraft are flying toward each other on opposite courses. The negative relationship is simply an attribute of the coding system used to classify the rating categories in the data analysis. A value of 1 was assigned to the highest Closure Rate, and a value of 4 was assigned to a Flight Path that was on a diverging/non-intersecting course. Another factor that contributed to the high correlation is the restricted range of points associated with Closure Rate and Flight Path. Nearly half of the OEs analyzed received no points for Closure Rate and 4 points for Flight Path.

Statistically, all of the correlations between the SI rating categories and the SI scores were significant ($p < .01$). Flight Path exhibited the highest correlations with the SI scores, ranging from a -.77 for the TE-Single-Site separation condition to -.78 for En Route 1,000 ft and 2,000 ft separation. Correlations between Closure Rate and the SI scores were similar to those for the Flight Path measure (ranging from .71 to .77). Overall, the lowest correlations between the SI rating categories and the SI scores were found for vertical separation (ranging from a -.14 to a -.41). The higher correlations between the SI and the Flight Path and Closure Rate variables suggest that they are relatively more important in determining the overall SI score. However, the overlap of these two variables suggests that once the contribution of one has been considered there would be little additional information provided by the other. Additionally, correlations between horizontal separation and the other SI measures were consistently higher than those between those measures and vertical separation. This suggests that the horizontal separation dimension may play a more prominent role in predicting the SI score of an OE than does the vertical separation.

Safety Margin

Figures 2-4 graphically illustrate the number of OEs that fell within each of the combined loss of separation standards categories. A scan of the En Route 1,000 ft and 2,000 ft separation figures (Figs. 2 and 3) reveals that a majority of the errors lie on the right-hand side involving 60% or more of the horizontal separation. For the TE-Single-Site separation condition (Figure 4) the errors exhibit greater spread across the two dimensions. Only a small number of OEs, from 0.7% (4/571) for En Route

2,000 ft to 10.5% (71/671) for TE-Single-Site separation, involved 30%, or less, of prescribed horizontal and vertical separation. As one could expect, due perhaps to the more restricted range of altitudes available for vertical separation, there was a higher percentage of OEs under the TE-Single-Site separation condition that involved less than 50% of the prescribed standards (36.3%) when compared with the En Route 1,000 ft (12.3%) and En Route 2,000 ft conditions (7.2%).

Figures 5 and 6 provide information regarding the average SI score based on percent of the required horizontal or vertical separation. With the exception of the values for the Wake Turbulence condition, the mean SI score declined linearly from an average of 80 to 90 for the three separation conditions to an average of 36 to 55 for horizontal separation (Fig. 5).

Changes in the average SI score for percent of vertical separation presented a much different picture (Fig. 6). For the categories involving 0 to 50% of the required vertical separation, the average SI scores for the three separation conditions (En Route 1,000 ft, En Route 2,000 ft, and TE-Single-Site) remain separate and fairly stable. Under the TE-Single-Site separation standards, the average SI score ranged from 76% to around 69% across the 0-10% through the 41-50% categories of vertical separation. Across the same categories, the average SI score ranged from around 59% to 63% for En Route 1,000 ft. The average SI for En Route 2,000 ft also evidenced a slight increase from 53 at 1-10% of vertical separation to 56 at 51-60%. From the 51-60% percent of vertical separation, the average SI score declined markedly to an average of 41-47 at 90% and above. The only exception is a score of 68 for the TE-Single-Site condition. This is the score for a single OE that fell within the 90% and above category.

These comparisons reveal the relatively greater importance of loss of horizontal separation in determining the overall SI score. SI scores increase in a relatively linear fashion for each 10% loss in horizontal separation. These changes are similar for each of the separation standards, with the exception of Wake Turbulence. Outcomes suggest that once there has been a 50% loss in the prescribed vertical separation, the continued loss of vertical separation contributes little to any overall increase in the SI score. The results also suggest that the loss of vertical separation may have a different influence in determining the SI score than horizontal separation. Additionally, loss of vertical separation may operate somewhat differently under the two En Route and TE-Single-Site separation conditions.

Rater Bias

Discriminant Analyses were conducted separately for the three separation standards: (1) High En Route (with a 2000 ft requirement, n = 73), (2) Low En Route (having a 1000 ft requirement, n = 126), and (3) Low En Route (having a 1000 ft requirement, n = 126), TE-Single-Site (n = 185). The predictor variables were Vertical Separation (V), Horizontal Separation (H), Flight Path (FP), Closure Rate (CR), and ATC Control (ATCC).

The resulting discriminant functions (L) are presented below.

$$\text{High En Route: } L = (1.34)V + (.83)H + (0)FP - (.78)CR + (0)ATCC.$$

$$\text{Low En Route: } L = (1.09)V + (1.02)H - (.77)FP - (.52)CR + (0)ATCC.$$

$$\text{TE-Single-Site: } L = (.61)V + (1.03)H - (.14)FP - (.34)CR + (0)ATCC.$$

As can be seen, the beta weights for elements of the SI that were included in the equations for the High En Route and Low En Route were similar. The only difference was that Flight Path played a more important role for Low En Route than for High En Route. Values for the High and Low En Route conditions differed substantially from the values included in the TE-Single-Site analysis. Horizontal separation played a much more critical role for the TE-Single-Site separation condition than in either of the other conditions. Overall, classification accuracy was 85% for both the Low and High En Route conditions. For the TE-Single-Site condition, classification accuracy was 92%. In all instances, these values were above those expected from the population base-rate. It should also be noted that weights of zero applied to ATCC and FP do not mean that these variables were not important classification variables. It just means that for SI values greater than 79, these variables became a constant and, thus, were not useful for differentiating between High Moderate and High Severity OEs.

CONCLUSION

The analyses conducted in an initial evaluation of the FAA's Severity Index (SI) reveal that a complex relationship exists among the individual components comprising the SI and the different separation standards within which the SI is applied. However, a consistent finding was the importance of horizontal separation to the overall SI score. The more horizontal separation there was, the less severe was the OE. This was especially true when using the TE-Single-Site Separation Standard. This conclusion was further supported by the results of the discriminant analyses. Greater weight was assigned to horizontal separation when classifying OEs into High Moderate and High categories using the TE-Single-Site Separation Standard.

Despite the importance of horizontal separation, the results of the discriminant analyses revealed that improvements to the SI might be obtained by developing a different weighting system for the three separation standards. For example, in Low En Route, the evidence suggested that vertical and horizontal separation should be weighted the same (as reflected in the current SI). Within High En Route, the evidence suggested that more weight should be given to vertical separation compared to horizontal separation. However, as previously mentioned, within TE-Single-Site more weight should be given to horizontal separation compared to vertical. It should be noted that this suggestion is based on analyses conducted for SI values greater than 79. Additional research is needed to explore this matter more fully and to determine whether similar results can be achieved using the entire range of the SI.

Finally, this evaluation of the FAA's Severity Index revealed that the SI provides a rational approach for categorizing the severity of ATC Operational Errors. Although questions remain as to the SI cut scores used to categorize OEs, it is recommended that they not be changed unless objective measures can be developed that support those changes. With the exception of the ATC Control component, the remaining four components are objective and are derived from performance characteristics of the aircraft involved in the OE. Additional research is needed to determine if the development of a checklist for the classification of the ATC Control factor would ensure a higher consistency of classification across individual controllers.

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¹This publication and all Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publications Web site:

<http://www.cami.jccbi.gov/aam-400A/index.html>

TABLES AND FIGURES

Table 1a. Radar OE severity index en route chart

VERTICAL SEPARATION 1,000 feet required	POINTS	HORIZONTAL SEPARATION 5-mile separation requirement	POINTS
500 feet to 599 feet	20	½ mile to 0.999 mile	25
600 feet to 699 feet	16	1 mile to 1.499 miles	24
700 feet to 799 feet	12	1.5 miles to 2 miles	24
800 feet to 899 feet	6	2 miles to 2.49 miles	23
900 feet to 999 feet	2	2.5 miles to 2,999 miles	22
VERTICAL SEPARATION 2,000 feet required		3 miles to 3.499 miles	20
Less than 500 feet	25	3.5 miles to 3,999 miles	16
500 feet to 599 feet	25	4 miles to 4,499 miles	10
600 feet to 699 feet	24	4.5 miles to 4,999 miles	5
700 feet to 799 feet	24	CLOSURE RATE	POINTS
800 feet to 899 feet	23	700 knots and greater	10
900 feet to 999 feet	22	300 knots to 699 knots	8
1,000 feet to 1,099 feet	20	100 knots to 299 knots	6
1,100 feet to 1,199 feet	18	Less than 100 knots	4
1,200 feet to 1,299 feet	16	FLIGHT PATHS	POINTS
1,300 feet to 1,399 feet	14	Converging – Opposite Courses	20
1,400 feet to 1,499 feet	12	Converging – Crossing Courses	18
1,500 feet to 1,599 feet	10	Same Course	10
1,600 feet to 1,699 feet	8	Diverging/Non-Intersecting	0
1,700 feet to 1,799 feet	6	ATC CONTROL FACTOR	POINTS
1,800 feet to 1,899 feet	4	Uncontrolled	20
1,900 feet to 1,999 feet	2	Controlled with TCAS RA	15
		Controlled with no TCAS RA	4

Standard separation in the en route environment is 5 nautical miles horizontally and 1,000 ft vertically up to 29,000 ft, and 2,000 feet vertically above 29,000 feet. All references to miles in this report are nautical miles. A nautical mile is equivalent to 6,076 ft.

Table 1b. Radar OE severity index terminal and en route single-site chart (TE-Single-Site)

VERTICAL SEPARATION	POINTS	HORIZONTAL SEPARATION 3-mile separation requirement	POINTS
Less than 500 feet	25	Less than $\frac{1}{2}$ mile	25
500 feet to 599 feet	20	$\frac{1}{2}$ mile to 0.999 mile	18
600 feet to 699 feet	16	1 mile to 1.499 miles	14
700 feet to 799 feet	12	1.5 miles to 2 miles	10
800 feet to 899 feet	6	2 miles to 2.49 miles	6
900 feet to 999 feet	2	2.5 miles to 2.999 miles	2
CLOSURE RATE	POINTS	HORIZONTAL SEPARATION 2.5-mile requirement	POINTS
700 knots and greater	10	Less than $\frac{1}{2}$ mile	25
300 knots to 699 knots	8	$\frac{1}{2}$ mile to 0.999 mile	20
100 knots to 299 knots	6	1 mile to 1.499 miles	16
Less than 100 knots	4	1.5 miles to 1.999 miles	10
FLIGHT PATHS	POINTS	2 miles to 2.499 miles	4
Converging – Opposite Courses	20	ATC CONTROL FACTOR	POINTS
Converging – Crossing Courses	18	Uncontrolled	20
Same Course	10	Controlled with TCAS RA	15
Diverging/Non-Intersecting	0	Controlled with no TCAS RA	4

* When wake turbulence separation standards are governing, **Do Not** include any vertical point value. Instead use the appropriate in trail separation index below, as well as other applicable factors" (FAA Order 7210.56, section 6-1-5).

IN TRAIL SEPARATION 4-mile separation requirement	POINTS	IN TRAIL SEPARATION 5-mile separation requirement	POINTS
3.49 miles or less	60	4.499 miles or less	60
3.5 miles to 3.999 miles	35	4.5 miles to 4.999 miles	35

IN TRAIL SEPARATION 4-mile separation requirement	POINTS
5.499 miles and less	60
5.5 miles to 5.999 miles	35

Table 2. Distribution of OEs across SI categories

Variable	Sub Category	Frequency	Percent	Mean	Std. Deviation
Vertical Sep.				621.14 ft.	484.49
Horizontal Sep.				2.93 miles	1.34
Closure Rate					
	700 or more Knots	50	2.51%		
	300–699 kts	270	13.53%		
	100–299 kts	352	17.63%		
	Less than 100 kts	373	18.69%		
	(Diverging)	951	47.64%		
Flight Path					
	Conv. – Opposite	104	5.21%		
	Conv. – Crossing	777	38.93%		
	Same Course	182	9.12%		
	Diverging/Non-Intersecting	933	46.74%		
ATC Control					
	Uncontrolled	1,414	70.84%		
	Controlled –	43	2.15%		
	TCAS RA				
	Controlled –	539	27.00%		
	No TCAS RA				

Table 3a. Correlations between SI measures for the En Route 1,000 ft Separation Standard

	SIVERT	SIHORZ	CTLFAC	FLTPATH	CRATE
SIVERT					
SIHORZ	-.118*				
CTLFAC	-.134*	.368*			
FLTPATH	-.047	.333*	.300*		
CRATE	.058	-.326*	-.281*	-.935*	
SI INDEX	-.216*	-.586*	-.614*	-.782*	.758*

* p<.01

Table 3b. Correlations between SI measures for the En Route 2,000 ft Separation Standard

	SIVERT	SIHORZ	CTLFAC	FLTPATH	CRATE
SIVERT					
SIHORZ	-.303*				
CTLFAC	-.048*	.326*			
FLTPATH	-.145*	.448*	.232*		
CRATE	.152*	-.439*	-.222*	-.971*	
SI INDEX	-.144*	-.589*	-.623*	-.782*	.773*

* p<.01

Table 3c. Correlations between SI measures for the TE-Single-Site Separation Standard

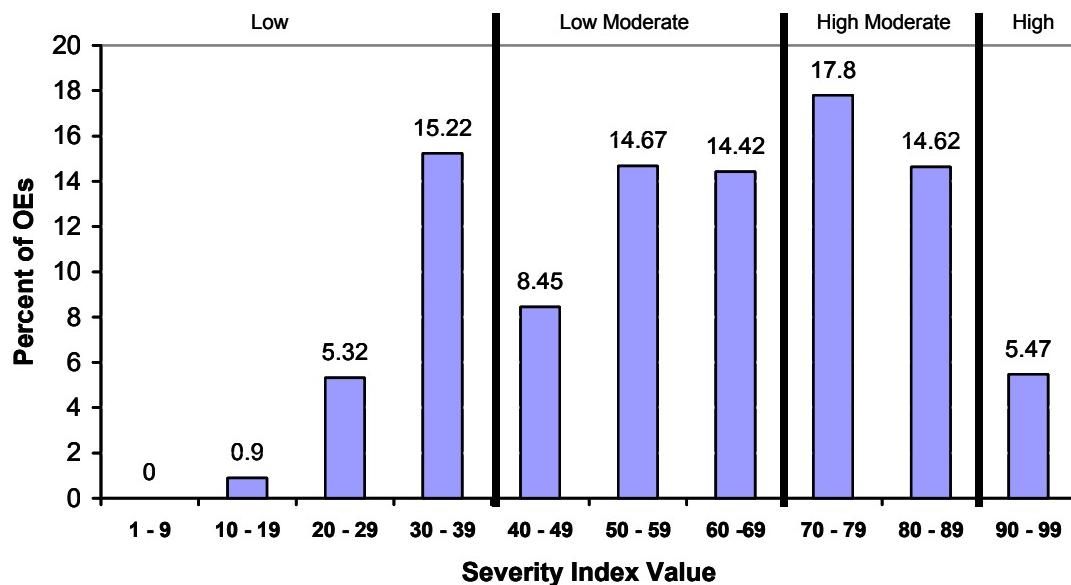
	SIVERT	SIHORZ	CTLFAC	FLTPATH	CRATE
SIVERT					
SIIHORZ	.266*				
CTLFAC	.125*	.350*			
FLTPATH	.134*	.476*	.304*		
CRATE	-.056	-.382*	-.272*	-.860*	
SI INDEX	-.411*	-.627*	-.597*	-.770*	.713*

* p<.01

Table 3d. Correlations between SI measures across all conditions

	SIVERT	SIHORZ	CTLFAC	FLTPATH	CRATE
SIVERT					
SIIHORZ	.147*				
CTLFAC	.082*	.401*			
FLTPATH	.119*	.539*	.337*		
CRATE	-.045	-.472*	-.307*	-.928*	
SI INDEX	-.320*	-.640*	-.635*	-.794*	.766*

* p<.01

**Figure 1.** Distribution of Severity Index values.

Low Altitude En Route

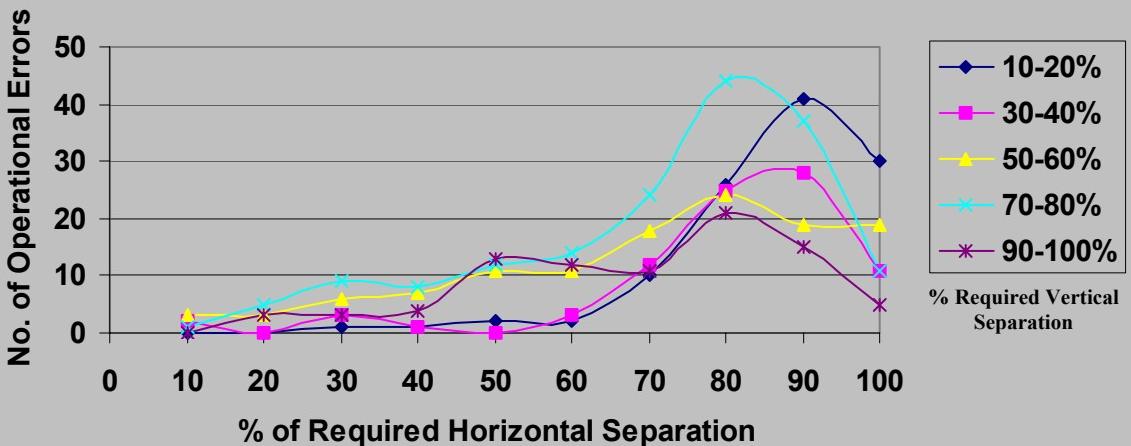


Figure 2. Distribution of operational errors (n= 719) by percent of required horizontal and vertical separation for low altitude en route with a 1000 ft vertical separation standard.

High Altitude En Route

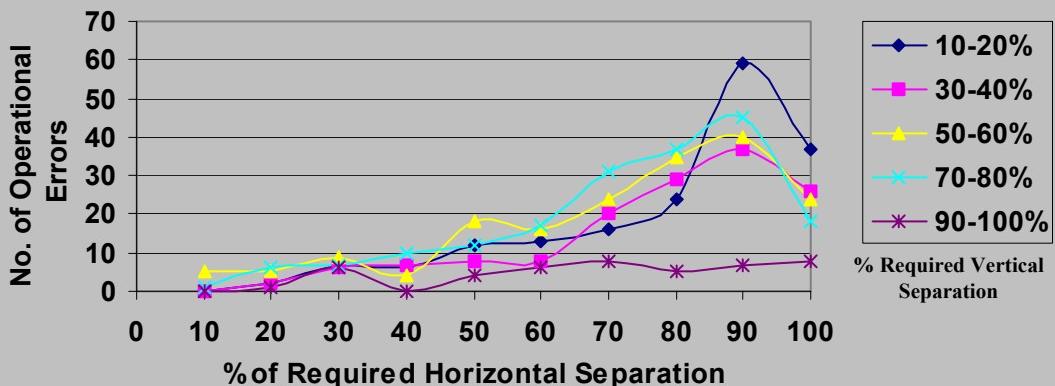


Figure 3. Distribution of operational errors (n = 571) by percent of required horizontal and vertical separation for high altitude en route with a 2000 ft vertical separation standard.

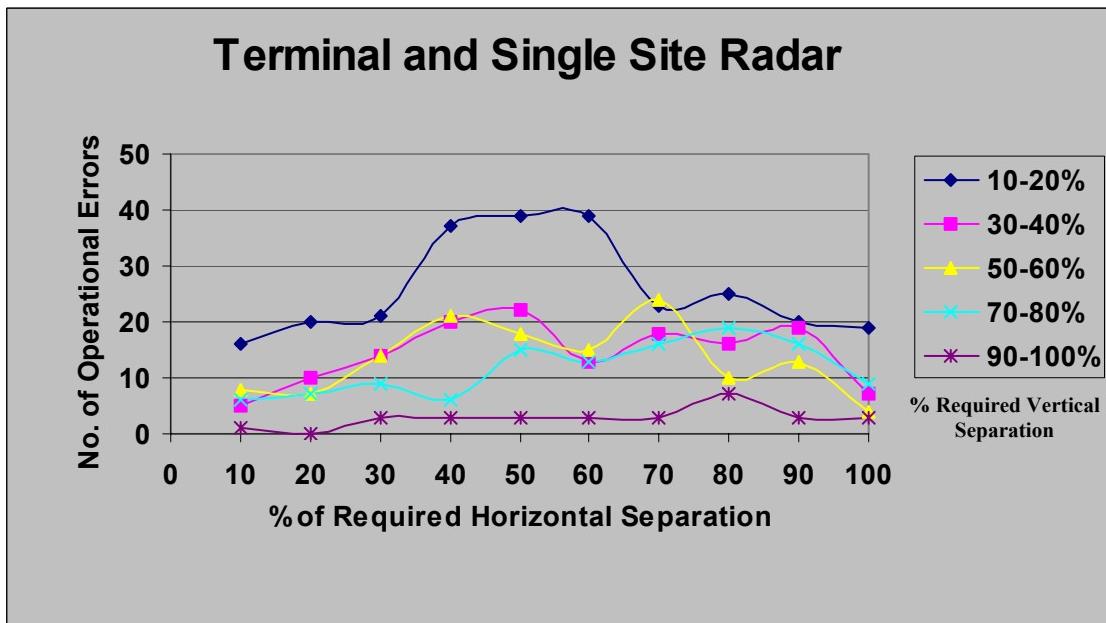


Figure 4. Distribution of operational errors ($n = 671$) by percent of required horizontal and vertical separation for Terminal and Single-Site Radar separation standard.

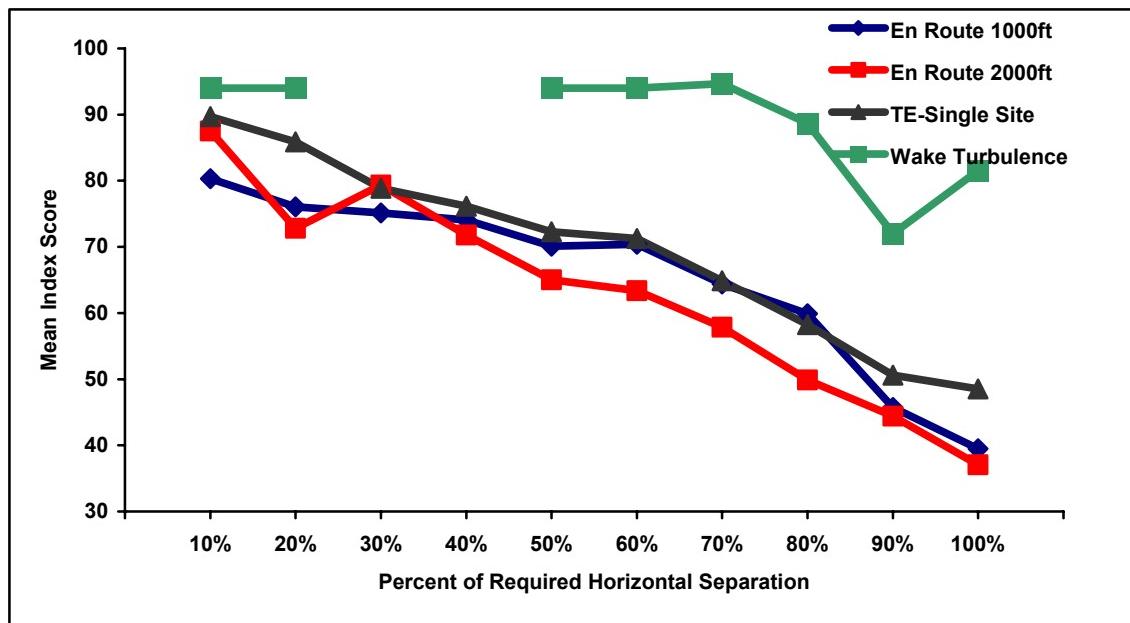


Figure 5. Average SI score based on percent of prescribed horizontal separation.

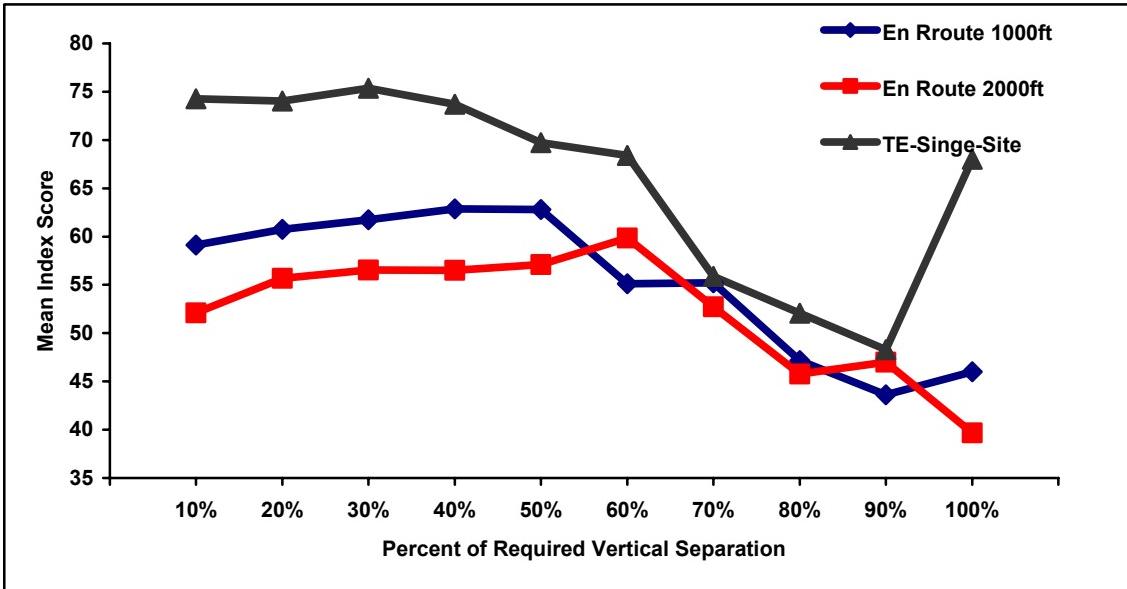


Figure 6. Average SI score based on percent of prescribed vertical separation.

